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A VISUAL BASIC SPREADSHEET MACRO FOR ESTIMATING GROUNDWATER RECHARGE

VISUAL BASIC MAKRO ZA PROCJENU NAPAJANJA PODZEMNE VODE

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Abstract

A Visual Basic spreadsheet macro was written to automate the estimation of groundwater recharge from stream or spring hydrographs using the adapted Meyboom's method. The program fits exponential regression model available in widely accessible platform (i.e. MS Excel) to baseflow recessions that precede and follow groundwater recharge, and uses regression equations to calculate recharge volume that occur between these recessions. An example of field data from Croatia (Bulaž spring) is given to illustrate its application.

Sažetak

Za procjenu količine napajanja podzemne vode na temelju hidrograma rijeke ili izvora izrađen je Visual Basic makro koji koristi prilagođenu Meyboomovu metodu. Program koristi eksponencijalni regresijski model, unutar široko dostupne platforme (MS Excel), za opis recesije baznog toka, koja slijedi nakon napajanja podzemne vode, te pomoću jednadžbi regresije računa volumen vode koji se prihrani između dvije recesije. Za prikaz rada aplikacije korišteni su podaci o količini istjecanja na izvoru Bulaž.

Introduction

Meyboom (1961) analyzed baseflow recession component of stream hydrograph of Elbow River in order to obtain a measure of groundwater recharge of the Calgary area (Alberta, Canada) using Boussinesqs (1877) exponential decay function. When discharge versus time plotted on semilogarithmic paper, recession expression becomes

$$Q = Q_0/10^{t/t_1} \tag{1}$$

where Q_0 is the discharge at time $t = 0$, t_1 is the time 1 log cycle later, and t equals any time of interest for which the value of Q is desired. Integration of equation (1) over the times of interest gives the total volume of baseflow discharge which corresponds to a given recession

$$Vol = \int_{t_0}^{t} Qdt = -\frac{Q_0 t_1 / 2.3}{10^{t/t_1}} \Big|_{t_0}^{t} \tag{2}$$

where t_0 is the starting time of interest. If equation (2) is integrated from time t_0 to infinity, the total volume of baseflow that would be discharged during an entire recession, if complete depletion were to take place uninterruptedly, can be computed. This volume is termed "total potential groundwater discharge" (Q_{tp}) and is given by

$$Q_{tp} = Q_0 t_1 / 2.3 \tag{3}$$

The volume of baseflow that is actually discharged through the total recession can be computed by integrating equation (2) from time t_0 to the end of recession. This volume is termed "actual groundwater discharge" (Q_a). Subtraction of total potential groundwater discharge (Q_{tp}) from actual groundwater discharge (Q_a) gives the "remaining potential groundwater discharge" (Q_r) at the end of the baseflow recession.

The recharge that takes place between recessions is the difference between the total potential groundwater discharge (Q_{tp}) at the beginning of any given baseflow recession and the remaining potential groundwater discharge (Q_r) at the end of the preceding baseflow recession. Equations (1), (2) and (3) were employed by Meyboom (1961) to estimate groundwater recharge between recessions.

In Meyboom's method, baseflow recession curves are derived manually, connecting successive points of minimum stream discharge, and are represented with straight lines on semilogarithmically plotted hydrograph. Such recession curves are used to calculate recharge volume that occur between recessions.

The adapted method presented in this paper consists in fitting exponential regression model available in widely accessible platform (i.e. MS Excel) to baseflow recessions that precede and follow groundwater recharge. The use of exponential regression model for derivation of baseflow recession curves (i.e. regression equations), enables automation of the calculation procedure and allows automated processing of large amount of data with little effort and time involved.

Similar programs for automated estimation of groundwater recharge (computer program RORA written in Fortran-77) were introduced in past years by Rutledge and Daniel (1994), Rutledge (1998), and Arnold and Allen (1999). The recharge algorithm they developed is an automated derivation of the Rorabaugh (1964) hydrograph recession curve displacement method that utilizes daily streamflow.

Program design

The VB Macro estimates groundwater recharge volume between two recessions using the adapted method applied by Meyboom (1961). After defining the data-processing periods, i.e. the baseflow recession period that precede and follow groundwater recharge period, the data are stored in separate spreadsheet ("Define" and "Prepare" in Fig. 1). This is followed by date conversion that converts absolute time into relative time equal to zero at the beginning of the analyzed recessions ("Date Conversion" in Fig. 1). Approximate recharge volume between these recessions is then calculated in the following manner ("Calculate" in Fig. 1): (1) exponential regression model is firstly fitted to recession that precedes groundwater recharge, hereafter referred to as the first recession; (2) total potential groundwater discharge (Q_{tp}) for the first recession is calculated using equation (3), where (Q_0) is the discharge at time $t = 0$ and the program reads it from the data set, (t_1) is the time 1 log cycle later and is given by

$$t_1 = (\ln(Q) - \ln(b)) / \ln(a) \tag{4}$$

where (Q) is the discharge at time (t_1) and is calculated from equation (1), and (a) and (b) are exponential regression equation constants calculated in step (1); (3) actual groundwater volume discharged through the total recession (Q_a) is given by

$$Q_a = (Q_0 t_1 / 2.3) - ((Q_0 t_1 / 2.3) / 10^{t/t_1}) \tag{5}$$

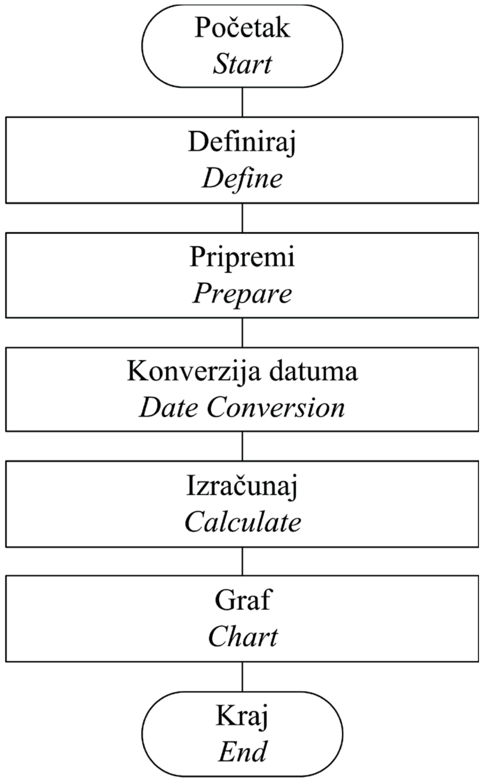

Figure 1 Program structure
Slika 1. *Struktura programa*

where (t) represents duration of total recession and the program reads it from the data set; (4) Remaining potential groundwater discharge (Q_r) at the end of the first recession is then calculated as the difference between total potential groundwater discharge and actual groundwater discharge, i.e. $Q_r = Q_{tp} - Q_a$; (5) in the next step exponential regression model is fitted to recession that follows groundwater recharge, hereafter referred to as the second recession; (6) total potential groundwater discharge for the second recession is calculated in the same manner as described above in step (2); (7) the recharge that takes place between two recessions is then calculated as the difference between total potential groundwater discharge (Q_{tp}) at the beginning of second recession and the remaining potential groundwater discharge (Q_r) at the end of the first recession. At the end of the processing program produces graphs showing first and second recession with exponential regression curves and regression equations ("Chart" in Fig. 1). All calculated values are also entered in spreadsheet.

Example

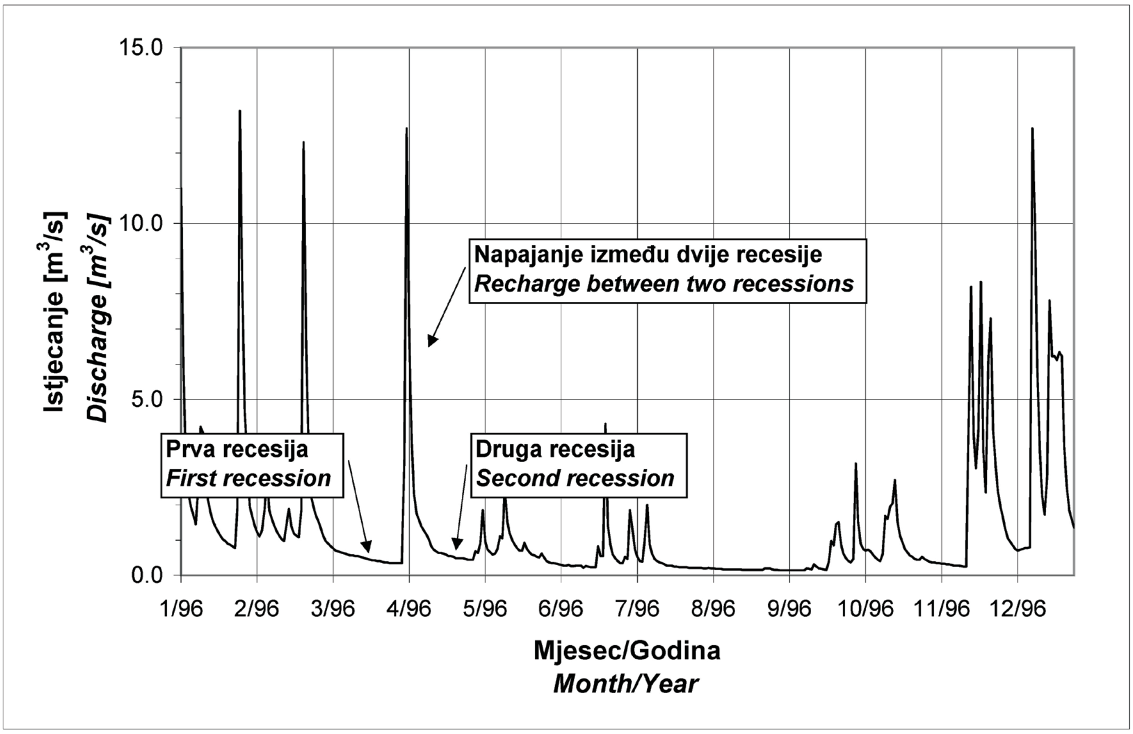

Figure 2 Hydrograph of Bulaž karst spring, Istria, Croatia
Slika 2. *Hidrogram krškog izvora Bulaž, Istra, Hrvatska*

Example illustrates estimating groundwater recharge from Bulaž karst spring hydrograph, located in Croatia. The Bulaž spring is a typical karst spring of the rising type. In regional sense, the appearance of spring is probably conditioned by the contact of flysch deposits with the Cretaceous limestones, although water appears at the contact of limestone and alluvial deposits of the Mirna river (sandy clay with clayey sand lens). The boundary and drainage area of spring were estimated on the basis of geological and structural relations, hydrogeological function of rocks, hydrogeological phenomena and the results of ground water tracing as well as research relation between average annual precipitation (1028 mm) and discharge rate. Accordingly, the estimated drainable area of 105 km^2, is composed of very permeable carbonate rocks (43 km^2) and nearly impermeable flysch sediments (62 km^2).

The outflow is very variable but the spring has never run dry. The high rates of outflow are the consequence of intensive precipitation and shows on quick drainage. In the dry period effect of the precipitation is weakly expressed. For the period from 1994 to 2001 the average annually discharge were 1,28 m^3/s, the minimum 5 l/s (7th September 2000) and the maximum 20,5 m^3/s (8th October 1998). The hydrograph peaks are explicit and short. They indicate on significant and rapid changes of outflow, with fast stabilization on relatively small and steady volume of the base flow.

Spring hydrograph for the year 1996 (Fig. 2) shows first and second recession that occurred in March and April, and groundwater recharge between these two recessions which is estimated in this example. After data processing, calculated groundwater recharge is entered in spreadsheet (Fig. 3). Columns A to G contain first and second recession data with relative times, while columns I to K contain calculation results for the first and second recession and calculated groundwater recharge. Graphs showing first and second recession with exponential regression curve and equation are created at the end of processing and also entered in spreadsheet. The recharge between two recessions (Fig. 3), drainage area (105 km^2) and average annual precipitation (1028 mm) indicate that the dynamic resources of the Bulaž spring are relatively small, because less than 5 % of precipitation can be stored in underground. The remaining part of the infiltrated water goes directly to the spring during high waters.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Recesija 1** ***Recession 1***				**Recesija 2** ***Recession 2***				**Recesija 1** ***Recession 1***					
2	Datum *Date*	Q [m³/s]	Relativno vrijeme [d] *Relative time [d]*		Datum *Date*	Q [m³/s]	Relativno vrijeme [d] *Relative time [d]*		Const. a	-0.02992				
3	02.03.1996	0.823	0		12.04.1996	0.823	0		Const. b	0.74536				
4	03.03.1996	0.774	1		13.04.1996	0.727	1		Q_0 =	0.823	m³/s			
5	04.03.1996	0.703	2		14.04.1996	0.680	2		$t_{(1 log)}$ =	74	[d]			
6	05.03.1996	0.680	3		15.04.1996	0.635	3		Q_{tp} =	2,276,517	m³			
7	06.03.1996	0.657	4		16.04.1996	0.635	4		t =	29	[d]			
8	07.03.1996	0.635	5		17.04.1996	0.613	5		Q_a =	1,357,259	m³			
9	08.03.1996	0.613	6		18.04.1996	0.591	6							
10	09.03.1996	0.591	7		19.04.1996	0.547	7		**Recesija 2** ***Recession 2***					
11	10.03.1996	0.569	8		20.04.1996	0.547	8		Const. a	-0.03337				
12	11.03.1996	0.569	9		21.04.1996	0.526	9		Const. b	0.73000				
13	12.03.1996	0.547	10		22.04.1996	0.485	10		Q_0 =	0.823	m³/s			
14	13.03.1996	0.547	11		23.04.1996	0.485	11		$t_{(1 log)}$ =	65	[d]			
15	14.03.1996	0.526	12		24.04.1996	0.485	12		Q_{tp} =	2,022,298	m³			
16	15.03.1996	0.505	13		25.04.1996	0.485	13							
17	16.03.1996	0.485	14		26.04.1996	0.464	14		**Napajanje između recesija** ***Recharge between recessions***					
18	17.03.1996	0.464	15		27.04.1996	0.444	15		R =	1,103,041	m³			
39														

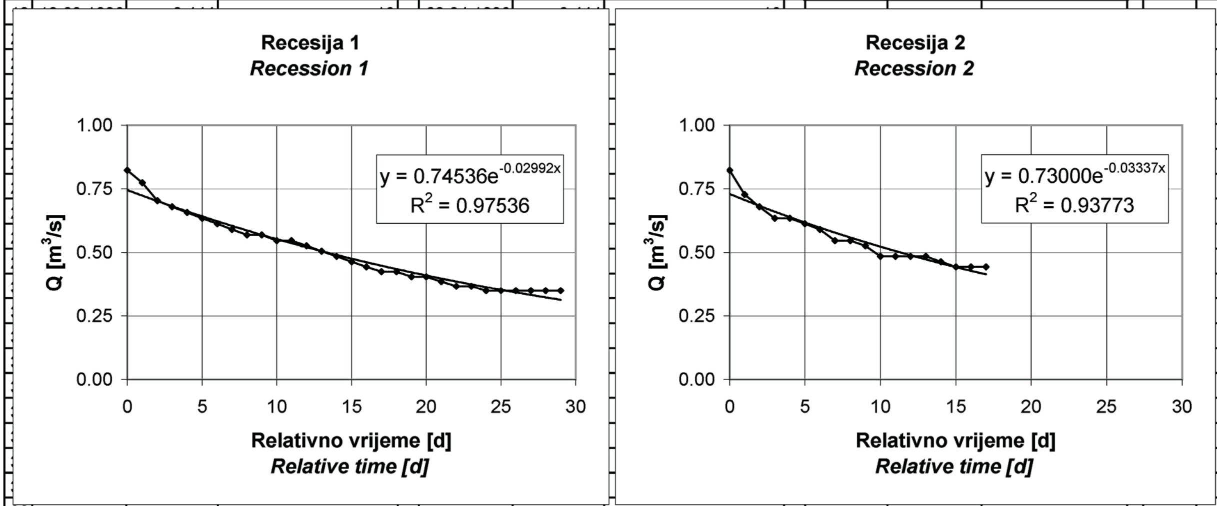

Figure 3 A spreadsheet example of estimated groundwater recharge
Slika 3. *Primjer procjene napajanja podzemne vode*

Conclusions

A VB program for estimating groundwater recharge from stream or spring hydrographs using the adapted method applied by Meyboom (1961) is described and applied to one example. The adapted method consists in fitting exponential regression model to baseflow recessions that precede and follow groundwater recharge. Regression equations are then used in calculating recharge volume using the same procedure as described by Meyboom (1961). This method gives quantitative information regarding the entities that make up the basic hydrologic equation, respectively show us that the dynamic resources of the Bulaž spring are relatively small. The VB macro automates tedious calculation procedure and report creation. The MS Excel platform chosen for the program is widely accessible which encourages wider use, and the user-friendly spreadsheet concept also makes it easy to use.

Software availability

The Excel spreadsheet with VB macro for estimating groundwater recharge between recessions may be requested without charge via e-mail to the corresponding author (kposavec@rgn.hr).

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